Monolith Rift

TVB-563

N E W S

Bangor Limestone

Hartselle Formation

Cave Pearls

1153asl

Flowstone
Floor

Monteagle Limestone

Entrances
1300asl
0 Datam

Rope Re-Belayed
To Small Tree On
South Side Of Pit
— 45ft Pit

20ft Pit
Rope Re-Belayed
To Flake To Left
Of Pit

1251asl

Old Boards

1227asl

1220asl

106ft Pit
Rig Rope To Bolts

Drop Continues
On Far Side
Of Boulder

1114asl

Mud And
Flowstone
Floor

1084asl — Tight 5ft
Vertical Slot

1055asl

Pair Of Tight
Spots With 7ft
Climbdown

1038asl

Steep Slope

1020asl

Breakdown Plugs

7ft Climbdown
Past Loose
Boulder

Difficult 10ft
Climbdown

8ft Climbdown
Over Stack Of
Loose Rocks

990asl — 15ft Climbdown

This Isometric Projection
Was Created On Interleaf
5.2 Software By:
David Parr

SURVEY DATA

Length: 618 feet
THC: 340 feet
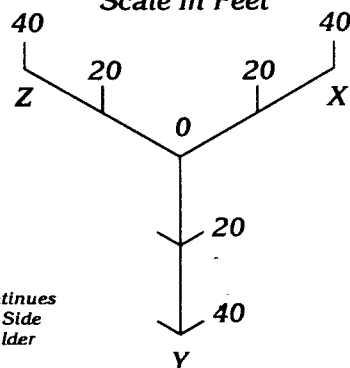Depth: 346 feet

Surveyed On March
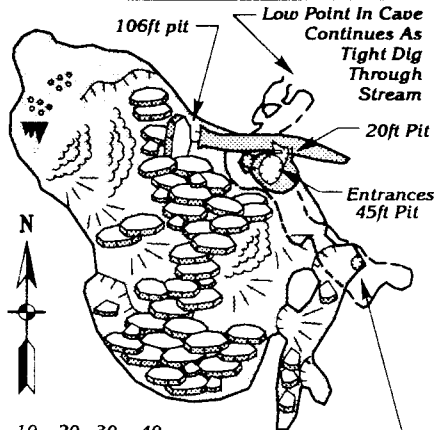The 2nd 1996 By:
Mark Richardson
John Stembel
David Parr
Jim Smith

Scale In Feet
40   40
  20   20
Z   X
0
20
40
Y

Plan View

106ft pit

Low Point In Cave
Continues As
Tight Dig
Through
Stream

20ft Pit

Entrances
45ft Pit

N

0 10 20 30 40
Scale In Feet

To Lower Level

To Lower Level

Lowest Point In Cave
954asl (-346ft)

Survey and Cartography Section

COMPASS & TAPE

The survey and Cartography Section (SACS) is an internal organization of the NSS that is devoted to improving the state of cave surveying and mapping.

MEMBERSHIP: Membership in the Section is open to anyone who is interested in surveying caves and in cave cartography. Membership in the National Speleological Society is not required.

DUES: Dues are $4.00 per year and include four issue of Compass & Tape. There are normally four issues of Compass & Tape each year, but if there are fewer, then all memberships will be extended to insure that four issues are received. Dues can be paid for up to 3 years ($12.00). Checks should be made payable to "SACS" and sent to the Treasurer.

COMPASS & TAPE: This is the Section's quarterly publication and is mailed to all members. It is normally published on a quarterly basis, but if insufficient material is available for an issue, the quarterly publication schedule may not be met. Compass & Tape includes articles covering a wide variety of topics including equipment reviews, hints and techniques, computer processing, mapping standards, artistic techniques, publications of interest, and appropriate material reprinted from local caving publications. It is the primary medium for conveying information and ideas within the cave mapping community. All membmers are strongly encourage to contribute material and to comment on published material. Items for publication should be submitted to the Editor.

NSS CONVENTION SESSION: SACS sponsors a Survey and Cartography session at each NSS Convention, at which papers are presented on a variety of topics of interest to the cave mapper. Everyone is welcome (and encouraged) to present a paper at the session. Contact the Vice Chair for additional information about presenting a paper.

ANNUAL SECTION MEETING: The Section holds its only formal meeting each year at the NSS Convention. All Section business, including election of Officers, is done at that meeting.

BACK ISSUES: SACS started in 1983 and copies of all back issues of Compass & Tape are available. the cost is $1.00 per issue, plus $0.50 postage for one issue or $1.00 for two or more issues ordered at once. Order back issues from the Treasurer.

OVERSEAS MEMBERS: SACS welcomes members from foreign countries. The rate for all foreign members is US$4.00 per year and SACS pays the cost of surface mailing of Compass & Tape. If you need air mail delivery, please inquire about rates. We regret that all checks must be payable in US$ and drawn on a U.S. bank.

CURRENT OFFICERS:

Chair:	**Carol Vesely, 817 Wildrose Ave., Monrovia, CA 91016-3022 (818) 357-6927**
Vice Chair:	**Roger Bartholomew, 910 Laurel Street, Rome, NY 13440 (315) 336-6551**
Secretary:	**George Dasher, 5096 W. Washington Street, #101, Cross Lanes, WV 25313, (304) 776-8048**
Treasurer:	**Bob Hoke, 6304 Kaybro Street, Laurel, MD 20707, (301) 725-5877**
Editor:	**Pat Kambesis, 2466 Drew Valley Road, Atlanta, GA, (404) 248-9538**

From the Editor:

Finally, because your editor stayed in town for a weekend you now hold the most recent issue of *Compass & Tape*. Contained within is a varied selection of articles that portray the wide range of subjects inclusive to the theme of survey and cartography (and you thought that this just included surveying caves and making maps!)

For those pesky survey errors that won't give you closure, read Larry Fish's article on ways to find those suckers. Dying to try out that new GPS unit? Bob Thrun has checked it out for you. Interested in knowing how to deal with caves where the backsite never matches the frontsite within reasonable tolerances? Kevin Allred tells what works for him in an article that should be entitled "Lava Tubes Ate My Boots." Also within these pages you will find out what gives Bill Mixon a headache, how your taxes are used to keep you confused, and creative ways to recycle non-functioning rapidograph pens.

But wait, there's more! Your chairman and I (a dangerous combination) have come up with a new section that we hope to continue in upcoming issues. Entitled "Cartographers Corner," this addition will focus on showing you some new, cool, and/or innovative features of maps. Yea, okay, so its just a thinly-veiled excuse to publish more cave maps - but there are enough good maps out there that we just might pull it off. Anyway, I'm sure that Carol will be surprised (and thrilled I hope) to see that her map is featured first (hey - it was partly her idea).

And finally, because I hail anyone who draws profiles with a bit of perspective, I just had to put David Parr's latest computer-drawn map on the front cover. If this is what one can do with a computer I may seriously consider "recycling" all of my drafting pens.

Inside:

Chairman's Message

I am pleased to see that *Compass & Tape* is alive and well. The last issue contained a wide variety of informative and thought-provoking articles, including four letters to the editor. And editor Pat Kambesis promises another round of intriguing material in this issue.

Some of you long-time Section members may recall several years ago when there was a real dearth of articles for the newsletter. This became an important topic at the annual SACS meeting at convention. Someone suggested that perhaps the reason for the lack of articles was that nearly everything that could be said about cave surveying and cartography had already been written. Basically, there was nothing left to write! There was even talk of discontinuing *Compass & Tape* and just providing back issues to new members. In retrospect, it is apparent that we were only going through one of the periodic lulls that happen to even the best of publications.

It is particularly gratifying to see so many people writing comments and responses to previous articles. Its nice to know people actually read the newsletter instead of just filing it away for future reference. *Compass & Tape* continues to serve as a valuable forum for the exchange of information and ideas on cave surveying and cartography.

Recently, Pat and I discussed the idea of publishing more cave maps in the newsletter. But simply publishing random, isolated maps seemed arbitrary and somewhat pointless. We finally came up with an idea that would be more interesting and informative. It involves publishing maps that display a ''new or improved'' technique, ones that illustrate how to handle a difficult cartographic situation, or maps that portray a particularly good example of a specific drafting method. Thus was born the idea of a ''Cartographers Corner'';

an ongoing feature that would describe specific cartographic techniques or innovations and would showcase one or two maps as examples. The purpose of Cartographers Corner is not to critique maps or make suggestions for improvements. Rather the intent is to highlight the best features of maps. We encourage your input. If you have a map that you admire for specific reasons, send it along with your comments to the editor.

I'd just like to add a few of my own comments about some of the articles in the last issue. In his discussion of the Cartography Salon, George Dasher states that he does not recall any first-time cartographer ever having received an award at the salon. I know of at least three. Ward Foeller won a MEDAL for his first cave map (William's, Cave, VA), Hazel Barton received a blue ribbon for her first-ever entry in 1995 (Fault Cave, Co.), and I won a Merit award for my first (Onyx Cave, PA). Although the standards for maps have become more stringent and the competition stiffer over the years, I still think it is possible for a cartographer to win an award for his or her first map. Nevertheless, I can appreciate Don Coons' frustration at the judging in the Salon. He is not the first one to put an incredible amount of talent and effort into a map only to be overlooked for an award.

Not only has winning the map salon become more difficult, but judging has also. I have judged the salon twice, in 1985 and 1991, and I noticed a definite difference. In the past, many more maps could be readily eliminated from the competition for not including the basics (north arrow, scale, labeled entrance, vertical control). With the quality of the maps improving year after year, it becomes more difficult to select the winners. The judges end up nit-picking about whether or not the legend should have a box around it! I'm not sure what the solution is. Perhaps, we should take a clue from the Photo Salon, and provide a basic recognition award for all maps that meet the Salon standards. If people really feel that the judging and awards need to be re-evaluated, we can address this issue at the annual meeting at convention. See you in Salida!

Carol Vesely, Chairman
Survey and Cartography Section.

Letters to the Editor

A Few More Comments on the NSS Cartographic Salon

Dear Editor:

I was very interested to read the discussion of the judging criteria of the NSS Cartographic Salon in *Compass & Tape Vol. 12, No. 3*. Don Coons raised several important questions and issues, and George Dasher, as salon chairman, provided a thoughtful reply. I'd waited six years for this discussion, since George and I co-chaired the committee which created the current standards in 1990. Based on that background, I'd like to add a little more perspective to the fray.

First, George stressed that the judging is subjective, but I'm afraid he over-emphasized it. The main purpose in developing the judging criteria was to give structure and objectivity to the salon. To avoid placing subjective regional biases in the criteria, the committee was comprised of cartographers from around the country. While any judging, by its nature, is infused with some subjectivity, and thus some standards will unfortunately change with the judges, the overall process should have a foundation of fairness and continuity that carries from year to year. In the salons I have judged or observed the judging, most disagreements between judges have been over relatively minor points, suggesting general fairness and objectivity. However, in a field of good to great entries, it is the minor points which inevitably distinguish the two.

Second, each salon is different. An unpredictable number and variety of caves and types of maps are entered each year. To accommodate this facet of the salon, the judges were given some discretionary power with the rules. While on the surface these may seem arbitrary, subjective decisions, I believe they meet their purpose of giving each salon the flexibility to meets its often unique needs for fair judging.

Third, Don raised the issue of the various degrees of difficulty in surveying caves and suggested that difficult caves should be given greater consideration by the judges. The committee discussed and experienced a heart-felt ache of sympathy for this position, but unanimously decided against it. This is the Cartographic Salon, not the Survey Salon. Regardless of the hardships in surveying, once behind the drafting table, the quality of the cartographer's work is not affected by bone-chilling water, 1000-meter descents, limited air supplies on SCUBA, or general physical exhaustion (and lousy notes are produced in easy caves too). Although the two are closley tied, the salon is judging maps - not caves.

Fourth, I agree with Don that a re-evaluation of our judging criteria is important, but also with George that now is not the time. The current process has only been used five times (not counting the preliminary version in 1989). With a few more rounds there will be many more good and bad points that we'll learn which will be useful to the rules revision. Besides, the questions involving the various forms of computer generated maps will likely spill into some aspects of the "standard" map judging as increasing numbers of future entries will be entirely computer drawn.

Fifth and finally, while emphasis at the salon is inevitably given to winning and losing, the real point of the current salon is learning. In 1989, I started the post-salon critique and the giving of critique forms to cartographers not to glorify the so-called "best-maps" but to create a forum where cartographers, judges and potential cartographers could discuss issues in pur-

"...while emphasis at the salon is inevitably given to winning and losing, the real point of the current salon is learning."

suit of excellence. The committee which created the criteria felt that excellent maps were informative, complete, well organized and balanced, skillfully and clearly drawn and labeled, and able to provide the viewer with a good overall impression of the character of the cave.

While artistry may enhance a map, it is not a requirement for excellence. Unfortunately, some cartographers and judges forget this fact and others critical to cave cartography and the Salon. We all clearly have much to learn, and well-considered discussions like that between Don and George will help advance our craft.

George Veni

Electronic Maps

Dear Editor,

One very important point seems to not have been made explicitly in the discussions about "electronic maps," by which I mean any map that could only have been made with computer assistance, whether or not it is presented in electronic form. That is the fact that, at the present state of the art, any judging will inevitably be based on the program, not the map, that is, on programming,

not cartography. There is nothing inherently wrong with that, and a competition among such programs might be useful in encouraging innovation, although there seems to be plenty of innovation without one. But everybody needs to be clear on just what is being judged.

If one does attempt to judge among programs, I'd hope he/she is very careful not to be sidetracked by "gee-whiz" issues and will concentrate on real utility. For example, being able to easily view a complex cave from any angle can be useful in understanding its general layout. Being able to "fly through" one on the screen seems pretty useless to me, and a continuously rotating display seems mainly conducive to a headache. A printed Toporobot map on display at the 1995 convention was an impressive display of technology. Unfortunately, it was incomprehensible.

A cave-map computer program should be judged on what genuine utility it provides that conventional maps do not and, to the extent that visualization is part of the alleged utility, on whether the display or printout bears any resemblance to a cave.

Good caving,

Bill Mixon
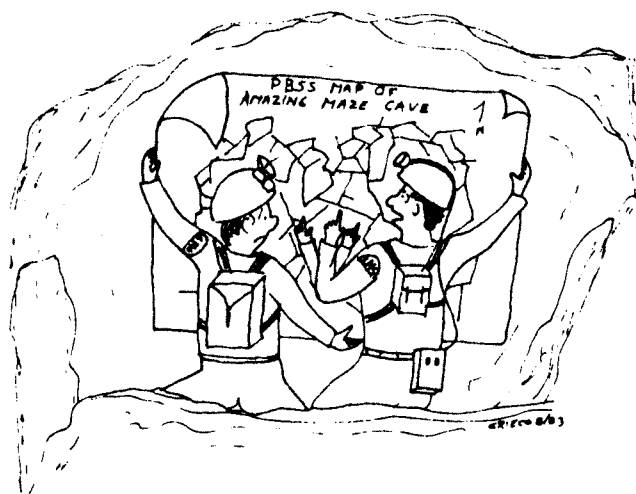
LOST? DON'T BE SILLY. ACCORDING TO THIS MAP WE'RE HERE ... AND HERE... AND HERE ...

BLUNDER LOCATION

by Larry Fish

The following document is an excerpt from an article called "The Program Groaning Wrote" that appeared in RockyMoutain Caving Autumn 1986. It has been updated slightly for read ability and accurancy. It was was also republished in Compass Points, a British technical caving magazine in 1995.

Introduction

In 1979 I started working on a project to computerize the survey data for Groaning Cave, Colorado. The cave had been discovered in 1969 and I was suddenly handed ten years of survey data that had never been processed by a computer. The early surveyors had processed all the information by hand and as a result, there were many anomolies and problems in the data.

When I looked at the Groaning data, I found that many loops near the front of the cave had large loop closure errors. Luckily, I had more than one survey for some of the worst loops and was able to compare good surveys to bad surveys of the same passage. Much to my surprise, the errors in the surveys were not due to the accumulation of small, random errors; but were due to major blunders like reading the wrong end of the compass needle, transposing digits on the survey notes, mixing up azimuth and elevation, etc. By comparing good surveys to bad , I could easily fix a bad survey by repairing the worst blunders one by one until the survey closed.

As I played with the idea more, I discovered that I didn't always need a good survey to find the blunders in a bad survey. I could see that each blunder leaves its own special mark on the closure error. For example, an azimuth error has no effect on the vertical component of the closure error, so a compass error can never produce a vertical error. If you have a survey with one blunder in it, the blunder will produce a very specific kind of closure error. For example, let say you have a 10-foot length blunder on a shot that has an azimuth of 130 degrees and inclination of -10 degrees, the closure error will be 10 feet on an azimuth of 130 degrees and an inclination of of-10 degrees. To find the blunder, all you have to do is find a shot that matches that measurement.

> **If you have a survey with one blunder in it, the blunder will produce a very specific kind of closure error.**

You can of course try to find matches by hand, but this is very tedious. In addition, matching azimuth and inclination is more complicated. It is much more useful to locate the errors using a computer. As a result, I have written a computer program that can locate blunders in survey loops.

The details of the computer technique used

adjusted, makes the loop error go down significantly. Therefore, you must adjust each measurement, one at a time, trying to get the most improvement for that particular measurement. The adjustment that makes the biggest improvement in the loop error is the most likely candidate to be the blunder for that loop.

Since you adjust each measurement one at a time, the adjustment is constrained by the other measurements in the shot. As a result, there is a limit to how much improvement each adjustment can produce. For example, if you test-adjust the azimuth of a 10-foot shot, the result must fall on a circle with a 10-foot radius. This constrains the possible improvement to the circle. If the measurement is not the blunder, it is very unlikely that the adjustment will significantly improve the loop error. This means that blunders leave unique signatures on the loop error. By going through the survey and adjusting each measurement in turn, you will find that most adjustments make modest improvements in the loop error. However, if you adjust the blundered measurement, it will produce a dramatic improvement in the loop error. Thus the BLUNDER program keeps track of the most successful adjustments. The best adjustments will always correspond with the worst blunders.

There are a few things that effect the ability of the program to locate blunders. First of all, the initial quality of the loop controls sensitivity of the program to blunders. If, aside for the blunder itself, the survey is of very high quality, the program can detect blunders as small as one foot or one degree. If, on the other hand, the survey quality is low, the blunders tend to get to get blurred by an accumulation of small random errors. In practice, this means you see several good candidates for blunders, instead of one.

Another thing that can effect the programs ability to locate blunders is when you have multiple blunders in the same loop. When this happens, the larger blunder tends to dominate and obscure the smaller one.

The Blunder Algorithm

The trick to this technique is to find simple routines that calculate the best adjustments for azimuth, inclination and length measurements. The following section describes the algorithms for finding the best adjustment for each measurement.

Azimuth Adjustment:

Figure 1 represents a closed cave survey loop. Point S is the start of the survey, point E is the end of the survey. The angle at A1 is the angle we are going to adjust. The object is to find how much to change angle A1 to produce the best closure.

Figure 1 - Adjusting Azimuth
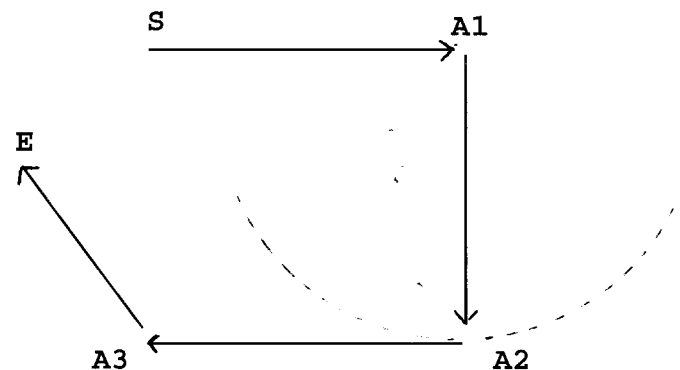
If we rotate angle A1 through 360 degrees, point A2 will describe a circle whose radius is equal to the distance between point A1 and point A2. Since the azimuth angle measurements in cave surveying are referenced to magnetic north, point A2 tends to be a hinge point. That is, as A1 is rotated, the angle at A2 also changes but every angle at every shot from A2 to the end of the

survey stays the same. As a result, as A1 is rotated, E describes a secondary circle whose center is offset from A1.

The secondary circle is important because it represents all possible points that E can occupy as we adjust angle A1. Thus, the best closure must be somewhere on its circumference.

In Figure 2, C represents the center of the secondary circle. This center is located by taking the offset between A2 and E and adding it to A1. To find the best closure, we must find the point on the circle that is closest to the starting point S. Since the shortest distance between any point and a circle must be on a radius, the best closure must be at the point where the line C - S intersects the circle.

closure, can be located using the triangle and polar coordinates. The new closure error is the distance between G and S, and the adjustment angle is the difference between angle G-C-H and angle E-C-H.
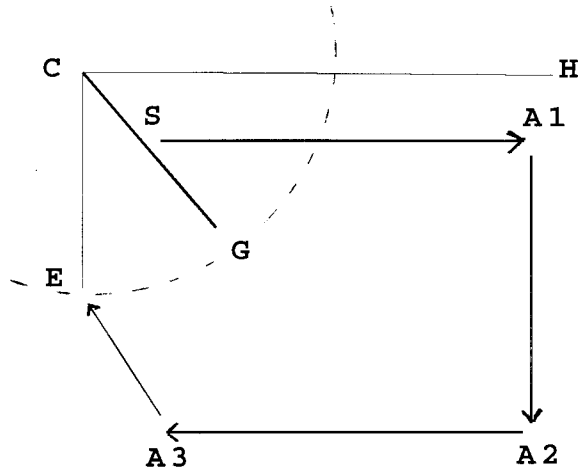
Figure 3 - Calculating The New Angle

Figure 2 - Secondary Circle

We know the locations of S, E, A1, A2, C and the radius, so all of the remaining points and angles can be calculated from this information.

In Figure 3, we construct a horizontal line from C to H; and using point S, we construct a right triangle. The location of G, the point of best

Length Adjustment:

Adjusting length is more complicated because the shot length has both the azimuth angle and dip angle effecting it. As a result, the shot length is actually a vector in three dimensional space. Adjusting a particular shot for best closure is, in some ways, similiar to adjusting azimuth.

For example, figure 4 represents a plan view of the survey, where S represents the start of the survey and E the end of the survey. The survey has a large survey error. If we attempt to minimize the closure error by adjusting the shot length of A1-A2, point E will move, drawing line L which represents all possible adjustments of the shot. Obviously, the best adjustment will give the short-est distance between point S and line L.

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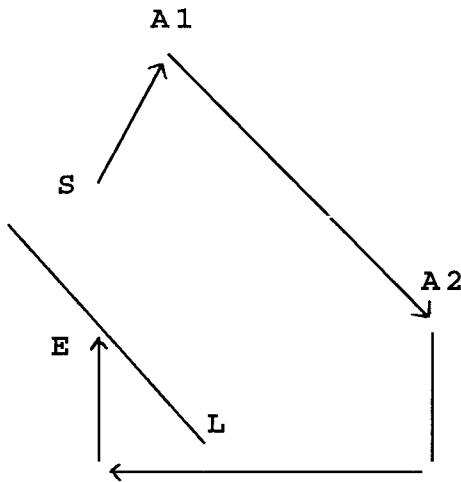
Figure 4 - Adjusting Length.

Since we are working in three dimensions, it is easiest to work using vector algebra. The shortest distance between a point and a line in 3-D space is given by the following formula:

$$d=|U \times V|$$

In other words, the distance from a line to a point is equal to the length of the cross product of the unit vector U and vector V. In this case, V is , the vector E-L and U is the unit vector for line A1-A2. Since A1-A2 and E-L are parallel, we define E-L from A1A2:

$$EL=DXi + DYj + DZk$$

From this we find the unit vector:

$$U= \frac{EL}{|EL|}$$

The distance is then calculated using the cross products:

$$d= |U \times ES|$$

Once we have found d, we have two sides of a right triangle and all other dimensions can be easily calculated.

Dip Adjustment:

Adjusting the dip angle is the most difficult part of the closure process. Since it is an angular adjustment, it is similar to the azimuth adjustment except that it takes place in three dimensions. This is because the inclinometer is free to rotate around the vertical axis, where as the compass is always held in the horizontal plane.

Figure 5 is a profile plot of a survey. The vertical or Z axis is toward the top of the page. Point S represents the start of the survey and point E represents the end of the survey. As you can see, there is a closure error between S and E.
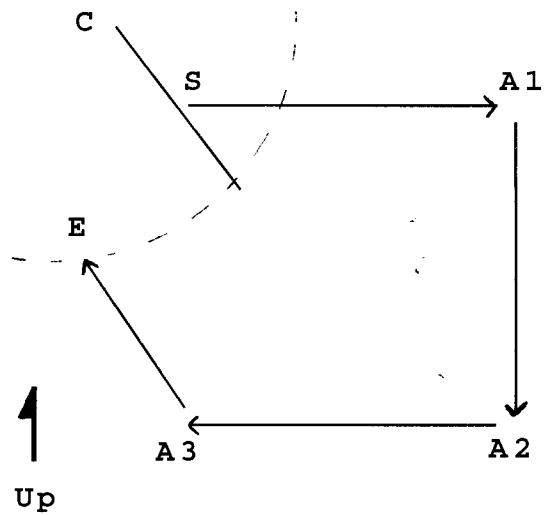
Figure 5 - Survey Profile.

In this example, A1 will be the dip angle that will be adjusted. As with the azimuth adjustment, when A1 is rotated through 360 degrees, A2 describes a circle with A1 as the center. Since all of the shots from A2 to E remain unchanged, as the adjustment is made, A2 will hinge and E will move through a secondary circle offset from A1. Since the secondary circle represents the result of all possible adjustments, the best closure must be

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some point on the secondary circle. The task is to find the closest point on the circle to the starting point S. This will be the best possible closure we can attain by adjusting the dip angle at A1.

Since the secondary circle and the starting point S are in three dimensions, the process of finding the closest point is more complex.

Figure 6 represents a three dimensional view of the secondary circle. Point S is the start of the survey and point E is the end of the survey.
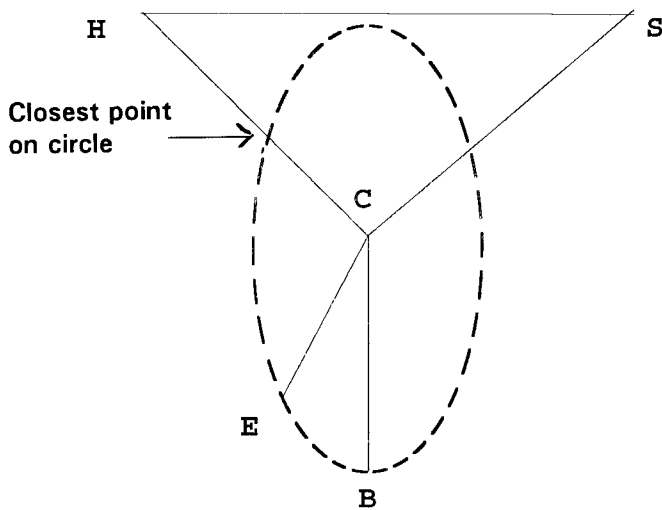
Figure 6 - Three dimensional view of secondary circle

The strategy for finding the closest point on the circle to S is to find the closest point from S to the plane of the circle. In the diagram, H is the closest point in plane of the circle to S. Now we calculate the intersect between H-C and the circle. This will be the closest point to S and will represent the best possible adjustment for this shot.

Since we know the location of E and can calculate the location of B and C, this gives us two vectors in the plane of the circle: C-B and C-E. By taking the cross product of CE and CB, we get a vector perpendicular to the plane. Taking the dot product of C-S and the unit vector of the perpendicular, we get the distance between S and the closest point on the plane: point H. Adding a perpendicular vector of length H-S to the coordinates for S gives us the coordinates for point H. With these coordinates, all other coordinates, angles and distances can be calculated.

In order to clarify the adjustment process, I have included the actual subroutines used in my loop closure program. The code is written in XPL a language syntactically similiar to Pascal and C. The code sample consists of three subroutines which correspond with each measurement in a shot. For example, "ADJAZM" finds the best adjustment for the azimuth of a shot. The subroutine is passed a pointer to the shot in question in the variable "SHOT".

Each subroutine returns an adjustment value for that particular measurement. The adjustment is stored in the global variable "ADJUST." The units of the adjustment depend on the type of measurement. For example, ADJUST will return degrees from the azimuth ajusting routine. The new error vector that results from each adjustment will be returned in VECERR.

The variables AZM(N), LEN(N), and DIP(N) are globals that hold the raw survey data. The variables EAST(N), NORTH(N), and VERTICAL(N) are globals that hold the cartesian coordinate for each station. The variable "RC" is used to convert between radians and degrees.

Program Listing

```
procedure ADJAZM(SHOT);
\Adjust the azimuth at SHOT
integer SHOT;
real
    NCENT,ECENT,    \CIRCLE CENTER
    OPS,ADJ,HYP,    \SIDES OF TRIANGLE
    A,B,            \SIDES OF TRIANGLE
    RADIUS,         \RADIUS OF CIRCLE
    PANGLE;         \POLAR ANGLE
begin
\LOCATE CENTER OF CIRCLE
NCENT:=NORTH(SHOT)+(NORTH(STAPTR-
1)-NORTH(SHOT+1));
ECENT:=EAST(SHOT)+(EAST(STAPTR-1)-
EAST(SHOT+1));

\CALCULATE RADIUS
A:=NORTH(SHOT)-NORTH(SHOT+1);
B:=EAST(SHOT)-EAST(SHOT+1);
RADIUS:=SQRT(SQR(A)+SQR(B));

\CONSTRUCT TRIANGLE AND FIND POLAR
ANGLE

Press RETURN for more; type NO to stop:
OPS:=NORTH(0)-NCENT;
ADJ:=EAST(0)-ECENT;
HYP:=SQRT(SQR(OPS)+SQR(ADJ));
PANGLE:=ATAN2(OPS,ADJ);

\CALCULATE NEW CLOSURE ERROR
ADJ:=HYP-RADIUS;
OPS:=VERTICLE(STAPTR-1)-VERTICLE(0);
VECERR:=SQRT(SQR(OPS)+SQR(ADJ));

\CALCULATE ADJUSTMENT ANGLE
OPS:=NORTH(STAPTR-1)-NCENT;
ADJ:=EAST(STAPTR-1)-ECENT;
ADJUST:=PANGLE-ATAN2(OPS,ADJ);
end;

procedure ADJLEN(SHOT);
\Adjust the length pointed by SHOT
integer SHOT;
real
    A1,B1,C1,       \VECTOR SHOT
    A2,B2,C2,       \VECTOR S-E
    A3,B3,C3,       \DISTANCE VECTOR
    AU,BU,CU,       \UNIT VECTOR OF SHOT
    SLEN,           \SHOT LENGTH
    CLEN;
begin
\CALCULATE SHOT VECTOR
A1:=EAST(SHOT+1)-EAST(SHOT);
B1:=NORTH(SHOT+1)-NORTH(SHOT);
C1:=VERTICAL(SHOT+1)-
VERTICAL(SHOT);

\GET SHOT LENGTH
SLEN:=SQRT(SQR(A1)+SQR(B1)+SQR(C1));

\GET UNIT VECTOR
AU:=A1/SLEN;
BU:=B1/SLEN;
CU:=C1/SLEN;

\CALCULATE VECTOR SE
A2:=EAST(0)-EAST(STAPTR-1);
B2:=NORTH(0)-NORTH(STAPTR-1);
C2:=VERTICAL(0)-VERTICAL(STAPTR-1);

\GET DISTANCE VECTOR
A3:=(BU*C2)-(CU*B2);
B3:=-((AU*C2)-(CU*A2));
C3:=(AU*B2)-(BU*A2);

\CALCULATE NEW CLOSURE ERROR
VECERR:=SQRT(SQR(A3)+SQR(B3)+SQR(C3));

\GET ADJUSTMENT
CLEN:=SQRT(SQR(A2)+SQR(B2)+SQR(C2));
ADJUST:=SQRT(SQR(CLEN)-SQR(VECERR));
end;

procedure ADJDIP(SHOT);
\Adjust the inclination pointed by SHOT
integer SHOT;
real
    NINT,EINT,VINT,     \INTERSECT COOR
    NCENT,ECENT,VCENT,  \CENTER OF
CIRCLE
    RADIUS,             \RADIUS OF CIRCLE
    A1,B1,C1,           \C-E VECTOR
    A2,B2,C2,           \C-B VECTOR
    A3,B3,C3,           \C-S VECTOR
```

```
        A4,B4,C4,      \S-I VECTOR
        A5,B5,C5,      \C-I VECTOR
        AP,BP,CP,      \PERPENDICULAR TO
CIRCLE
        TLEN;          \LENGTH TEMP
begin
\GET CENTER AND RADIUS OF CIRCLE
NCENT:=NORTH(SHOT)+(NORTH(STAPTR-
1)-NORTH(SHOT+1));
ECENT:=EAST(SHOT)+(EAST(STAPTR-1)-
EAST(SHOT+1));
VCENT:=VERTICAL(SHOT)+(VERTICAL(STAPTR-
1)-VERTICAL(SHOT+1));
RADIUS:=LEN(SHOT);


\GET 2 VECTORS IN CIRCLE PLANE
A1:=EAST(STAPTR-1)-ECENT;
B1:=NORTH(STAPTR-1)-NCENT;


C1:=VERTICAL(STAPTR-1)-VCENT;


if (RLABS(A1)<1E-4) & (RLABS(B1)<1E-4)
then
    begin
      A2:=SIN(AZM(SHOT)/RC)*RADIUS;
      B2:=COS(AZM(SHOT)/RC)*RADIUS;
      C2:=0.;
    end
else  [A2:=0.;B2:=0.;C2:=-RADIUS;];


\GET PERPENDICULAR WITH CROSS PROD-
UCT


AP:=((B1*C2)-(C1*B2));
BP:=-((A1*C2)-(C1*A2));
CP:=((A1*B2)-(B1*A2));


\CONVERT TO UNIT VECTOR
TLEN:=SQRT(SQR(AP)+SQR(BP)+SQR(CP));


AP:=AP/TLEN;
BP:=BP/TLEN;
CP:=CP/TLEN;


\GET VECTOR C-S
A3:=EAST(0)-ECENT;
B3:=NORTH(0)-NCENT;
C3:=VERTICAL(0)-VCENT;


\GET DISTANCE WITH DOT PRODUCT
TLEN:=(AP*A3)+(BP*B3)+(CP*C3);


\GET VECTOR FROM START TO INTERSECT
A4:=AP*TLEN;
B4:=BP*TLEN;
C4:=CP*TLEN;


\GET INTERSECT COORDINATES
EINT:=EAST(0)-A4;
NINT:=NORTH(0)-B4;
VINT:=VERTICAL(0)-C4;


\GET VECTOR C-I
A5:=EINT-ECENT;
B5:=NINT-NCENT;
C5:=VINT-VCENT;


\CONVERT TO VECTOR BETWEEN C AND
CIRCLE INTERSECT
TLEN:=SQRT(SQR(A5)+SQR(B5)+SQR(C5));
A5:=(A5/TLEN)*RADIUS;
B5:=(B5/TLEN)*RADIUS;
C5:=(C5/TLEN)*RADIUS;


\GET INTERSECT WITH CIRCLE
EINT:=ECENT+A5;
NINT:=NCENT+B5;
VINT:=VCENT+C5;


\CALCULATE ERROR
VECERR:=SQRT(SQR(EINT-EAST(0))
+SQR(NINT-NORTH(0))+SQR(VINT-VERTI-
CAL(0)));


\CALCULATE ANGLE BETWEEN CI AND CE
ADJUST:=ACOS(((A1*A5)+(B1*B5)+(C1*C5))/
SQR(RADIUS));
end;
```

The Accuracy of GPS Receivers and an Attempt at Do-It-Yourself Differential GPS

by Robert Thrun
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This article is being submitted simultaneously to *Compass & Tape* and the British *Compass Points*.

A lot of cavers are starting to use Global Positioning System (GPS) receivers to determine cave locations with the intent of being able to easily find the caves again. This article discusses the accuracy of GPS locations and two methods to improve the accuracy: averaging and the use of two receivers.

Background

The United States Department of Defense (DOD) has put up 24 satellites that make up the Global Positioning System. The GPS satellites transmit precisely timed signals along with their orbital coordinates. The GPS receiver measures the arrival time differences and uses them to get its location relative to the satellites' locations. The receiver gives its location in either latitude or Universal Transverse Mercator coordinates.

The advertising literature from some of the GPS manufacturers makes it difficult to get a simple answer to "How accurate is it?" Each manufacturer seems to state the accuracy in a different way: root-mean-square error, or circular error probability, and it is not clear if they are quoting nominal DOD specifications, giving best-case results, or giving worst-case results. The DOD accuracy specification could be quoted, but to get real-world accuracy figures, we have to actually log GPS results.

The accuracy of GPS is not as good as what most cavers would like. In particular, DOD imposes Selective Availability (SA) upon the signals sent down from the satellites. SA is a deliberate degradation of the accuracy of the signals so that they will be less useful to potential enemies. Very strangely, SA was turned off during the Gulf War and the Haiti invasion, two times when we would most want to confuse the enemy.

Many users want to get more accurate locations than are given by GPS with Selective Availability. The standard way of doing this is to use Differential GPS (DGPS). The US Coast Guard feels that better accuracy is needed for some harbor approaches, so they have set up a system of beacons to broad-

> **Thus we have the ridiculous situation where one government agency, the DOD, puts up a very accurate navigation system, deliberately degrades it, and two other agencies work to undo the degradation.**

cast correction information. The DGPS receiver costs about $500 and connects to the GPS receiver. This is what is meant when a GPS receiver is advertised as "differential-ready".

The Coast Guard beacons are located along the coasts and the Mississippi River, not in the mountain areas where we go caving. The Federal Aviation Administration plans to install DGPS beacons at airports. Thus we have the ridiculous situation where one government agency, the DOD, puts up a very accurate navigation system, deliberately degrades it, and two other agencies work to undo the degradation. There are some private companies that provide a broadcast correction service, but they do not yet cover the inland caving areas.

The Coast Guard DGPS supposedly provides accuracy to 5 or 10 meters. Even better accuracy can be had from GPS receivers meant for surveying use. Two-meter accuracy is claimed for the survey units. Somewhat better survey units can get accuracy of a few centimeters by using phase measurement techniques on the signals. Some really high-end units claim 0.5 mm accuracy.

The survey DGPS receivers store the raw data from satellites, which can be post-processed to get the differential corrections. Some of the units have sufficient internal memory to store readings at 1-second intervals for most of a day. The prices for the survey units start at about $3000. A phase-measurement unit is over $5000, and prices go up to about $50,000. To do DGPS, you need two receivers, but it is not necessary to buy two receivers. Many states provide the service of fixed base stations recording GPS data. Surveyors can subscribe to this data.

Experiments

Bob Hoke bought a Garmin 75 receiver, and I bought a slightly newer Garmin 45. As of this

Figure 1. Data collected with Garmin 45 on February 12.
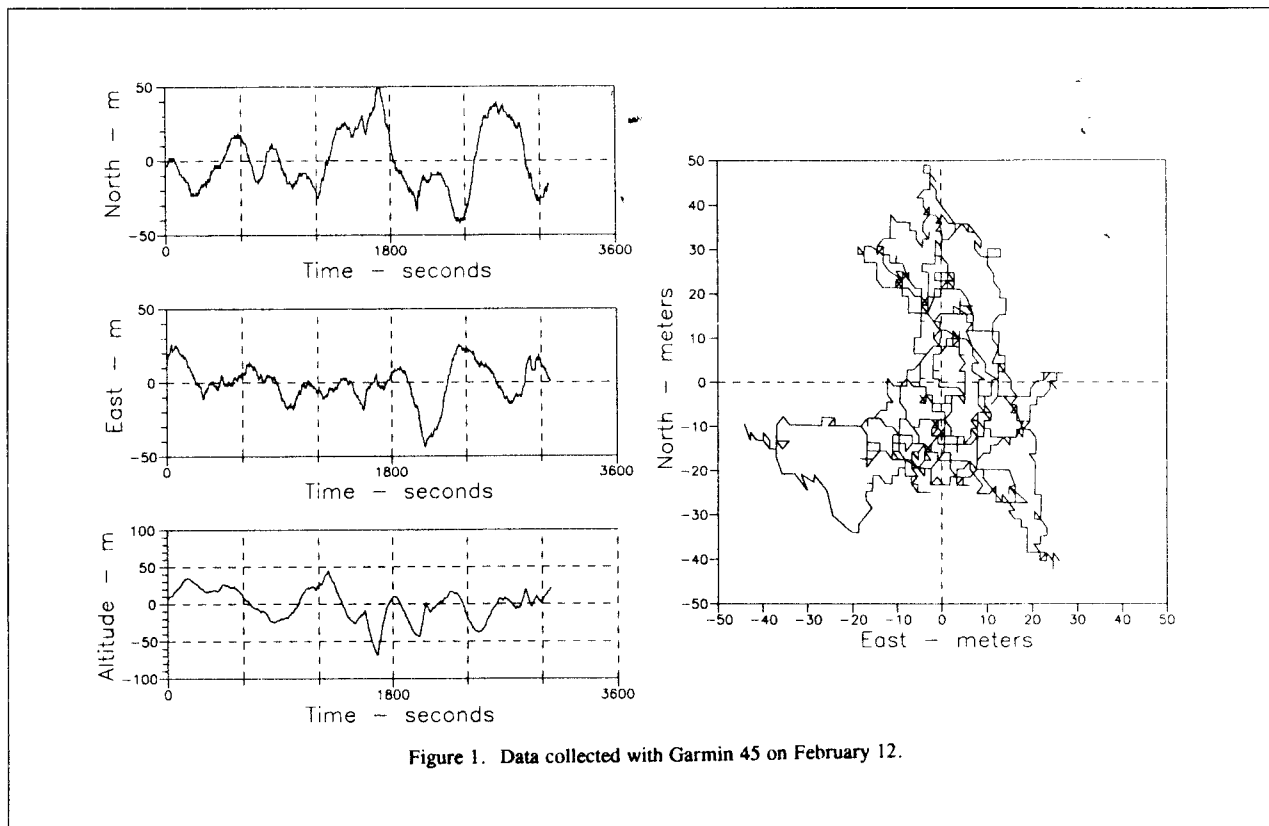
writing, the Garmin 45 is one of the lowest priced receivers on the market at about $300.

Since the low end of the market is dominated by marine users, most of the receivers have a serial port that puts out a data stream in one or more of the formats specified by the National Marine Electronics Association (NMEA). The NMEA data stream may be captured by any communications program. The Garmin 45 gives latitude and longitude to 0.001 minute. The older Garmin 75 gives locations to 0.01 minute. The coordinates are given once approximately every two seconds. A program was written to convert the latitude-longitude data to meters in the Universal Transverse Mercator (UTM) system and subtract the average for the session. In all the figures in this article, the average location has been subtracted from the data.

Many GPS receivers can periodically store locations as waypoints along a track. The stored waypoints can be downloaded to a computer using a proprietary protocol. This does not require carrying a computer into the field. For this study computers were used to capture the NMEA data stream in order to collect the maximum amount of data.

Figure 1 shows the data that were obtained from the Garmin 45 during a 50-minute session on February 12, 1995. The three plots on the left show the individual north, east, and altitude components of the location after the average location was subtracted. The plot on the right shows the map view (north and east) coordinates. The receiver was stationary during the session, but it gave a location that wandered around. The GPS locations could be enclosed in a 70 by 100 meter rectangle. The average was about 11 meters from the location that was read as carefully as possible from a 1:24000 topographic map.

The variation is rapid enough so that we can't

Figure 2. Data collected with Garmin 45 on May 6.
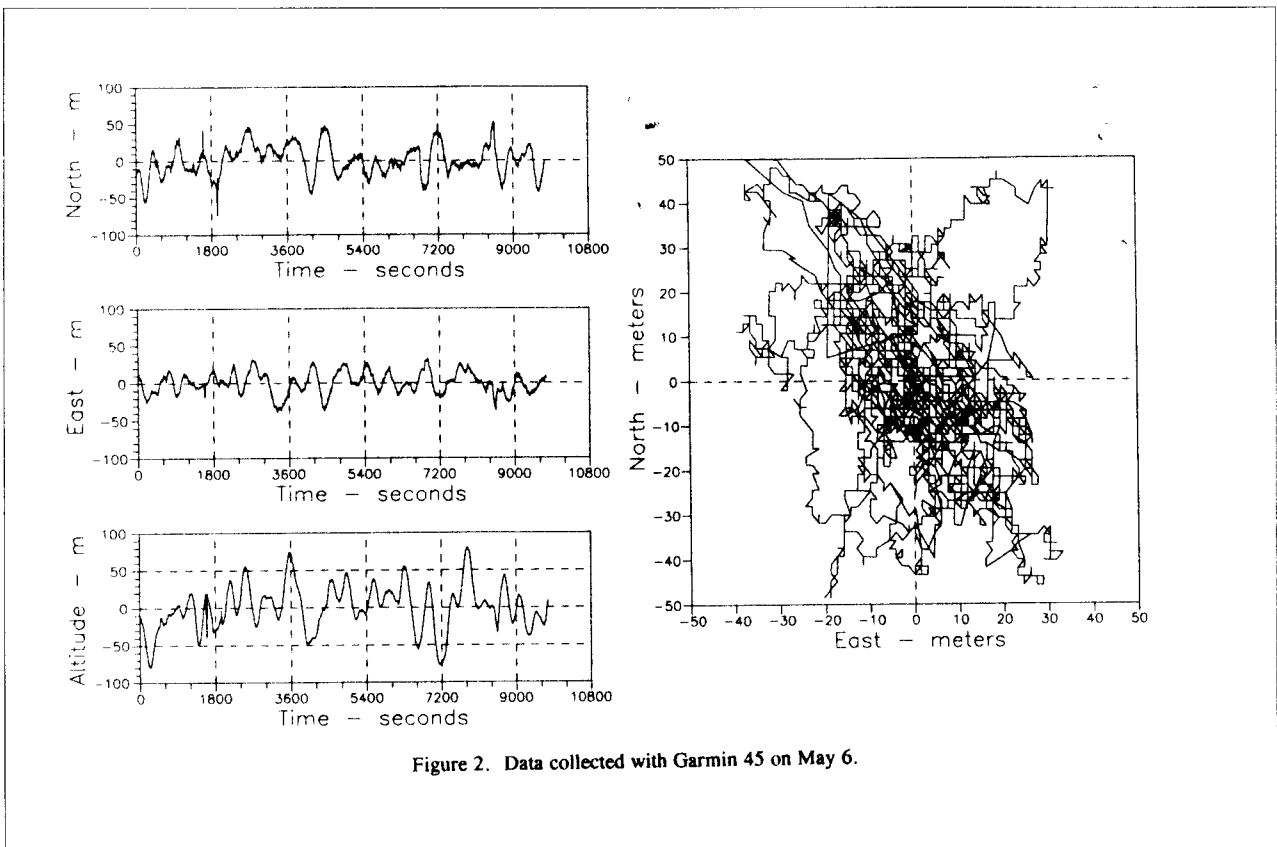
go from a benchmark, to the cave, back to the benchmark and then interpolate with time to get the correction. This is what we would do with altimeters, because atmospheric pressure varies slowly, but GPS locations vary too rapidly.

The less technical descriptions of DGPS make sound like it is simply a matter of taking the difference between the coordinates from two receivers. Most cavers can only afford the cheap GPS units. We thought that it should be possible to do DGPS by logging the coordinates from two cheap units to computers. When I called one of the manufacturers about this possibility, the technician pointed out that the two receivers must be using the same set of satellites. The cheap receivers will accept the differential corrections, but they will not put out the corrections.

Some of the more technical literature points out that the order of correction operations is important and that the corrections should be applied to the raw data. The survey systems do post-processing with the raw survey data. Obviously, the cheap GPS units must be using the raw satellite data internally, but they do not put that out. I suspect that there are only a few lines of firmware and a fair chunk of memory difference between the marine units and the survey units. Some manufacturers even use the same plastic cases.

Despite the suggestions that it might not be the best way to do things, we decided to try a Do-It-Yourself (DIY) DGPS with two cheap receivers on the possibility that might provide a significant improvement over the accuracy of a single receiver. On May 6, the Garmin 45 was set up in the same location as in February. This was a near-ideal site. It was on the roof of a car in a large empty parking lot. Seven or eight satellites were usable at all times. Data were logged for over 2.5 hours. The coordinates with the average subtracted are shown in Figure 2. The spikes at
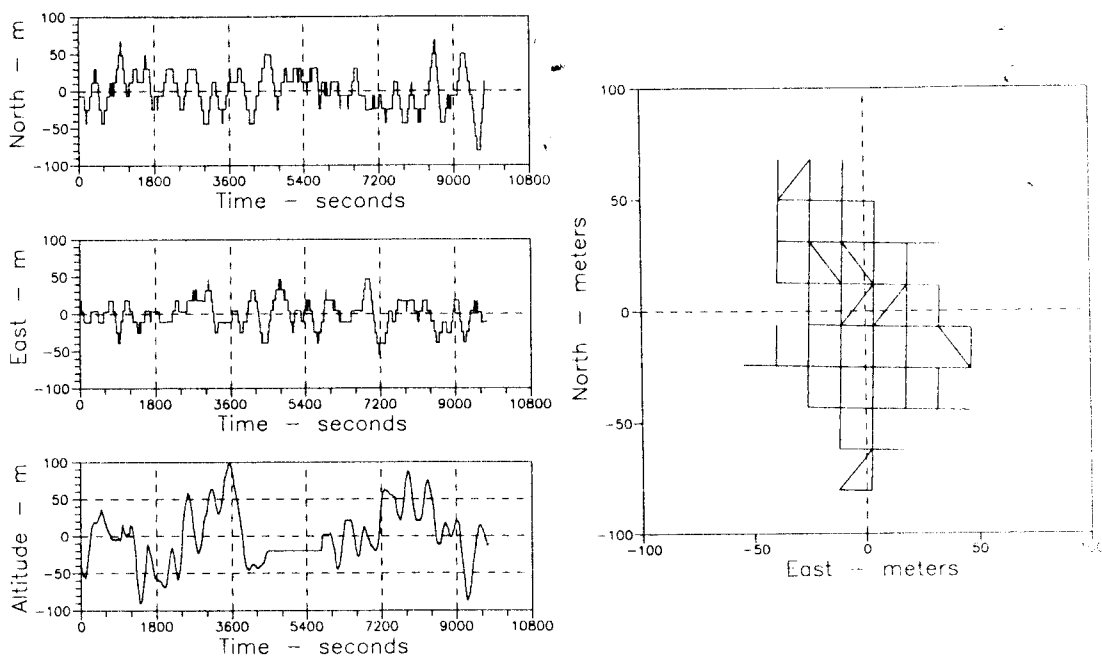

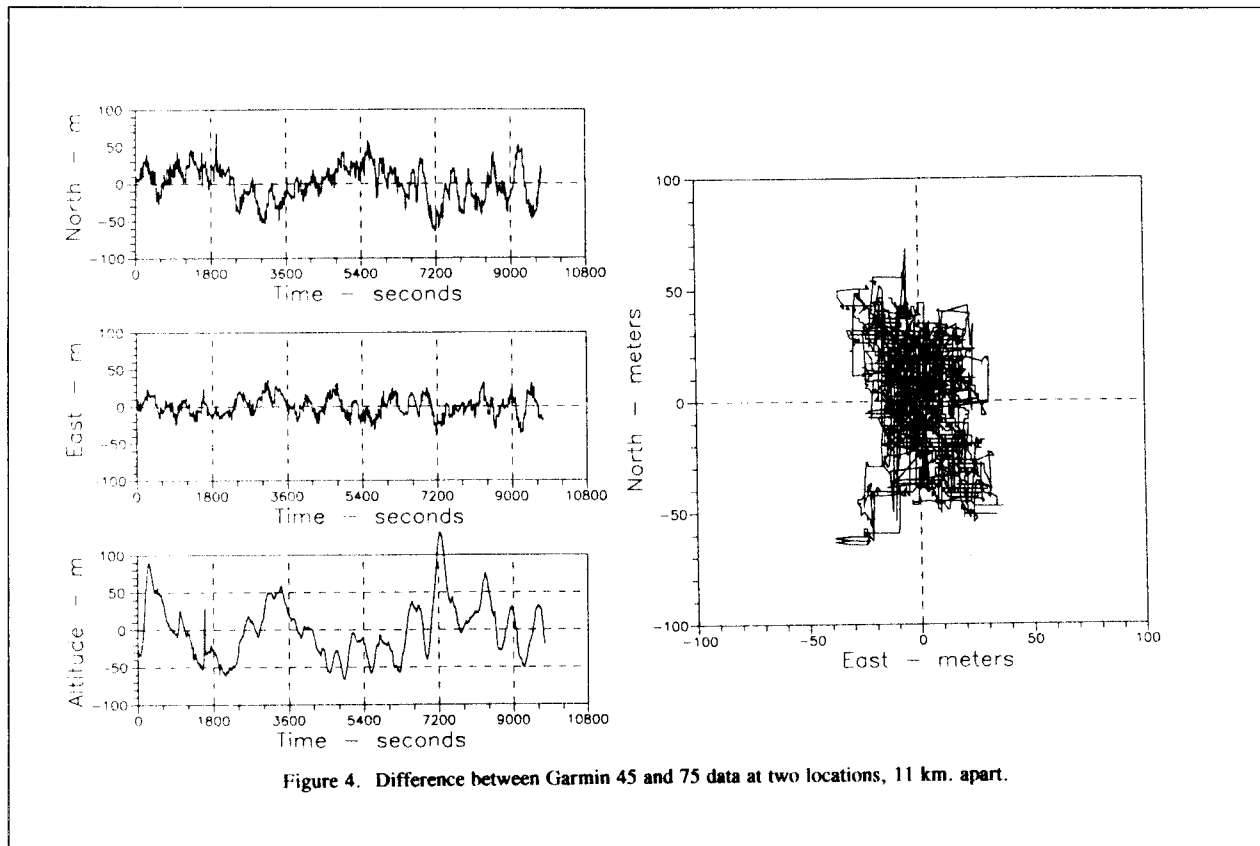Figure 3. Data collected with Garmin 75 on May 6

Figure 4. Difference between Garmin 45 and 75 data at two locations, 11 km. apart.

around 900 seconds are due to experimenting with battery-saver mode while the unit was running. Again, the coordinates could be enclosed in about a 70 by 100 meter rectangle. The averaged location was 15 meters from the location that was read from the topo map and 5.95 meters from the February average.

Also on May 6, the Garmin 75 was set up near a house in a residential neighborhood about 11 kilometers from the Garmin 45. The Garmin 75 location had houses and trees as obstructions. Its data were logged for a longer period that overlapped the Garmin 45 data, so we are able to make a comparison at the same times. The coordinates with the average subtracted are shown in Figure 3. Because the latitude and longitude were reported to 0.01 minute at the serial port, the coordinates change in steps ten times larger that the Garmin 45. A 0.01 minute rectangle is 14.411 by 18.498 meters. The Garmin 75 reports to better accuracy on its front panel display. The

coordinates from the Garmin 75 varied more than the Garmin 45. The section starting at about 4500 seconds where the altitude does not change indicates that the unit could not see the four satellites that necessary for 3-dimensional navigation and went into 2-D mode. Because of this data and because we could see obstructions, we are sure that the two units were not seeing the same set of satellites.

When we compare Figures 2 and 3, we can see that there is a high degree of correlation between the coordinate variations of the two receivers at some times, but there are also times when they differed greatly. The differences between the Garmin 45 and 75, again with the average subtracted, are shown in Figure 4. The differences do not show much of an improvement over the raw data. Even where it looks like the two units are dead on, as for the altitudes around 2500 or 3600 seconds, there is about a 20-second difference between the curves. The lag might be related to the fact that the Garmin receivers do multiplexing.

The conclusion is that this attempt at DIY DGPS did not work. Another trial with identical receivers where both have good coverage might work, but we certainly can't count on it. We can only hope for the prices on surveying GPS units to come down. The only real difference between marine units and survey units is the internal memory for saving raw data.

A comparison with the average tells us about consistency, not accuracy. Reading a location from a map has errors of its own. To get an idea of absolute accuracy, the Garmin 45 was set up at a geodetic benchmark on Spruce Knob, the highest point in West Virginia, on September 4, 1995. Receiving conditions were good, with 6 or 7 satellites in use at all times. The results of that session are shown in Figure 5. The latitude and longitude of the benchmark were gotten from the National Geodetic Survey. The averaged GPS location was 11 meters due west of the actual

location. The logging was interrupted to save the data to disk, giving four sessions of 15, 16, 18, and 31 mimutes with locations 23, 9, 20, and 3 meters from the actual location.   Averaging

It is evident that the average locations are reasonably accurate. How often and for how long should we sample? I'll express my opinion. You should refer to the figures to follow my reasoning.

The sampling should be frequent enough so that more frequent sampling will not change the average. This means that we should have points on all of the peaks and during times of rapid change. The maximum number of waypoints that can be stored in the GPS receiver could limit the number of samples that can be taken. Otherwise, we would just sample as frequently as possible. From the figures, it looks like every 10 to 30 seconds is a reasonable rate.

Figure 5. Data collected with Garmin 45 on Spruce Knob, September 4.
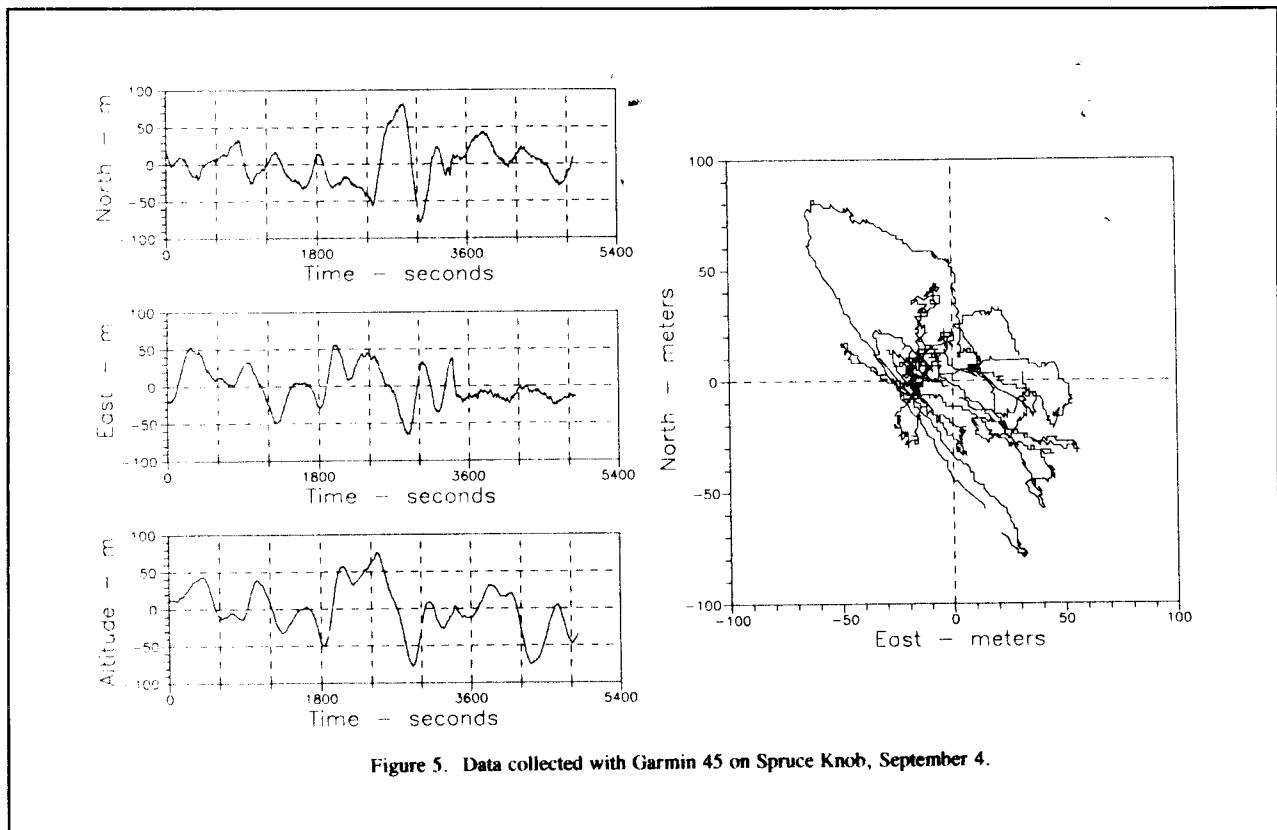
The duration must be longer than the longest peak. Otherwise, we might as well just take one reading. A 10 minute session would get the average off the peak. The duration should cover at least one complete cycle of the longest-period coordinate changes that we see in our logs in order to get a zero average for a cycle. More cycles would be better. The coordinate changes are very irregular, but it looks like a 30-minute logging session would cover the longest cycle.

Conclusions

A single GPS location has 50 to 100 meter accuracy. Averaging can increase the accuracy to 10 to 20 meters. The data should be averaged for at least 30 minutes with 10 to 30 seconds between samples, with 10 minutes being the shortest period for which averaging is of any benefit.

The traditional way of locating caves is to plot their location on topographic maps and measure their coordinates on the map. If good maps are available and locations can be plotted relative to easily distinguished topographic features, the tra-

ditional method is better than GPS. There are some valid reasons for using GPS, such as featureless areas or areas with poor maps. Until Selective Availability is turned off or the price of surveying GPS units comes down, we will continue to use topographic maps as the primary method for locating caves with GPS as a check for blunders.

P.S. The White House announced on March 29, 1996 that the most precise GPS data will be made available to civilian users. Press accounts did not make it clear exactly what this would involve. The military has two channels of encrypted Precision Code (P-code) on two different frequencies. Civilians have another channel of Coarse Acquisition (C/A) signals. The C/A signals are inherently less accurate than P-code, and the C/A signals are further degraded by Selective Availability. The new policy will be phased in over four to ten years. Selective Availability could be turned off in a few hours as the GPS satellites pass over ground stations. Use of the P-Code would require a new generation of receivers for civilian use.

"NOW THAT'S WHAT I CALL AN ACURATE MAP!"

Why Have Lava Tube Survey Standards?

by Kevin Allred

Recently, Carlene Allred and I have done a lot of surveying in the lava tubes of Hawaii. When we realized help was needed to finish surveying Kazumura Cave in reasonable time, we felt it important to prepare others as much as possible before they began mapping with us by letting them know some of the qualities we are aiming for in our finished maps. We had found challenges in lava tube surveying not usually found in carbonate caves.

Most horizontal caves of any kind were traditionally surveyed with only plan views and sometimes without even measured inclinations. The rationalization was that since the cave was horizontal, or nearly so, why bother to do something not really needed in order to portray the cave. However, we are learning from experience that regardless of the shape of a cave, both profile and plan view along with inlincations are absolutely necessary to understand and "see" passages on paper. As we slowly, but surely worked on Kazumura with our standards, wonderful things started to unfold. Soon, we could more easily know where to find new passage, dig major connnections to extend the system, and understand how the features in the cave formed. We were paying a higher price timewise, but getting bigger rewards.

Surveying has become the only way to really explore the cave, and we're hooked on the means. As we study other maps of lava tubes to compare them to Kazumura, the only ones that are useful are those few with plan, profiles, and cross sections. To those who take the time do do it right, please keep up the great work so we can -"see" what your caves are really like.

KAZUMURA CAVE PROJECT OF THE HSS
- SURVEY STANDARDS

In order to make an accurate map, surveys must be concise, and notes complete. Please finish the entire area you are working in systematically. THE RULE IS, SURVEY EVERYTHING THAT YOU CAN GET THROUGH WITH YOUR HELMET ON YOUR HEAD. If it looks good, you can dig and/or push it harder. We realize that the low passages are truly tortuous, but we are doing them anyway.

Bring extra footwear, several tee shirts, a couple pair of pants, and a couple of long sleeve shirts. We have found that the tee shirts can be worn over the long sleeved shirts for extra protection. Knee pads and gloves are needed, and possibly elbow pads as well. Temperatures are maybe about 60 degrees F and will lower as we continue in elevation. Bring vertical gear for pitches up to 50 feet with 20 foot overhangs. We

have plenty of rope on the Island. We also are using an extension ladder for high leads. Bring a set of poly pro for the many wet days anticipated. Most of us have been using electric headlamps with D cells. Use the brighter type bulbs available as the lava soaks up light more than you can believe. As a guideline, you can just make out walls 20 feet away with the dim bulbs.

Nearly all of the survey points should be marked with small, marked flagging (we plan on taking these out when we are sure no more side/ overhead connections are possible), and any unsurveyed leads should be marked with a long piece of flagging stretched part way across the passage so we can know to survey it or tie it into a side/ upper passage. We are committed to a good job, and will re-survey portions if they are not done right. Where the survey ends each day, a long piece of flagging is stretched across the passage. That way a return trip will easily find the point. We are using fiberglass tapes in feet and tenths. Bring your own instruments (water-proofed) and tape at least 100 feet long with an extra tape refill along with 6 ring-binder and survey pouch. You are welcome to donate rite-in-rain pages, as this Project has no budget.

INSTRUMENTS PERSON

1. Avoid sighting with a large steel reflector on your headlamp, or other magnetic steel such as a justrite headlamp. Keep flashlights and other magnetic objects away from the compass. Watch out for headlamp battery packs! Kazumura Cave has inconsistent magnetic anomalies with fore and backshot discrepancies of up to 10 degrees. The best we can do to rectify this problem is to just try and be accurate and use overland surveys to known geographical references. So far, we have made 5 of these control points for the cave system. When possible, we keep the compass away from the rock, but do not know if this really helps.

2. If you wish, you may want to take both back and fore shots, but it is up to your own judgment. Double check all measurements relayed to the sketcher. Azimuth and inclinometer readings are in degrees. Remember that if the inclinometer reading is backwards, the survey will be twice as wrong vertically. Be sure that your inclinometer is the type that reads 90 degrees when you view it straight up.

3. Have only one eye open when sighting with compass. Keep the compass level.

4. Make sure survey gear is in the pack before leaving camp.

5. Compass declination must be set at zero if you insist on using a Brunton.

LEAD PERSON

1. Don't forget to bring flagging and marker for marking survey points.

2. Mark and label the entrance point/s. Also mark points at all leads and dig sites by securing marked flagging out of the way of traffic from both directions.

3. Double check tape measurements.

4. Tie into a previous survey.

5. Contraction cracks occur every few feet along the walls. Cracks about one eight of an inch are ideal to hang the end of the tape in. These can be chosen as ideal points, especially at eye level.

6. Don't get carried away running down the passage past leads. Please spot them and put a point near them. We do not want to re-

survey down the main passages to get to a lead 20 feet long. Leads up to 20 feet or so can just be sketched and not surveyed. It is best to get these guys surveyed systematically as you go. Mike Shambaugh found that a penlight with a tag of duct tape and small nails stuck through the tape makes a good point light to hang off the first survey point. This leaves the sketcher free to sketch while the point man is running out the tape, setting a new point, and sighting the instruments. The sketcher can take a moment and turn off the penlight when the readings are done.

7. The shots will be longer and easier to place if the survey points are chosen so that they are somewhere on the outside walls of bends rather than the inside of the bends. If the stretched tape is left hanging from the points, a more exact compass reading is possible by sighting under the tape (and away from the wall).

SKETCHER

1. You control the survey and are responsible to note any special features. There are three words to keep in mind. They are accuracy, detail, and redundancy. Record all survey points on both plan and profile. This double checks any blunders in listing the points elsewhere. Record backshots on both the azimuth and inclination (when indicated). This double checks any blunders in the plan and profile views. Survey points can be abbreviated such as recording "M", rather than "B233M" (however, somewhere on each page should be the complete designation if pages are ever mixed up). Record the depths of drops and ledges. Flow ledges are different than levies which usually occur on the floor near entrances or former

entrances. You do not need to put drop depths on levies if they are less than one foot high. We seem to be seeing less of the levee features as we go up the mountain. The symbol for levies are straight lines without tick marks. It may be good to note where the levies begin and end or fade to insignificance.

2. Double check relayed measurements by calling out the readings and getting a confirmation.

3. Sketch to one inch equals 50 feet, marking your scale. Mark a north arrow on each page. Number each survey point. Include both plan and running profile views to scale. Figure 1, is an example of a running profile. You may use a protractor and ruler for accuracy. It is your job to catch survey blunders while sketching. NOTE: lava tubes are almost always sinuously graceful and not faceted. Walls and ceiling are usually very uniform and smooth, especially in lower passage. The stretched survey tape should usually be left hanging or allowed to fall straight down so the sketcher can get the passage curves oriented correctly in relation to the straight
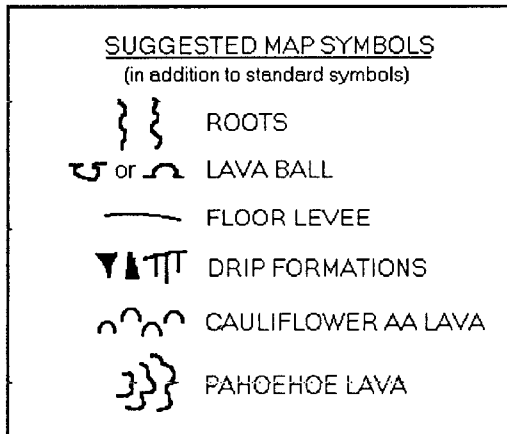

FIGURE 1
running profile
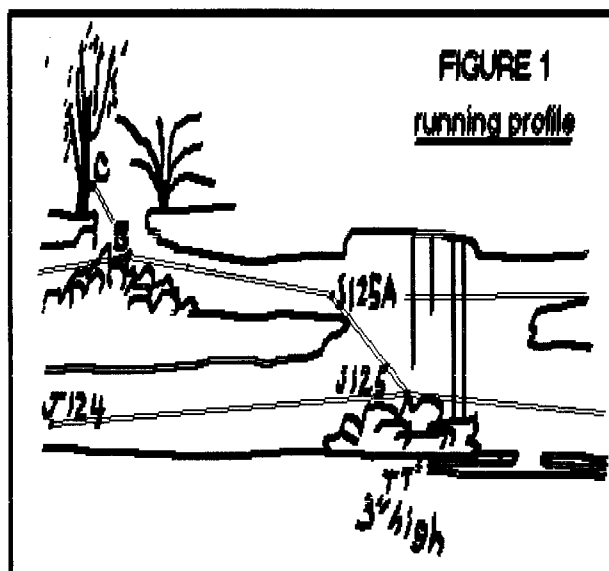
during which time the lead person can be reeling up behind me. In order to do this the reel should be left with the sketcher at all times, and wedged behind/under a rock or projection, while the lead person unreels.

4. Notes shall be returned to the appropriate place at the close of each day. The new cave entrances should be pinpointed on a topo map if they are going to be used for new entry points. In addition the sketcher should draw a map from that entrance to the nearest road. Each expedition, we have screwed up on surveys with bad instruments, blunders, or substandard surveys. This last time, we will have to re-survey about one mile. We need to get it right the first time if possible! Overland surveys MUST have both inclinations and compass readings to be worth anything. A quick sketch of the overland survey would be very good for redundancy. A sketch of important overland features is also helpful, and helps catch blunders.

5. Higher, fossil passage is often hidden in alcoves behind breakdown high above the floor. Check carefully for these. Some are real miserable, but need pushing. These can be both tributaries and effluent passages. Significant mazes have been found in these.

6. Measure or estimate distance to walls, ceiling and floor perpendicular to survey travel. See Figure 2 for an illustration of these measurements. Noting if the measures are to breakdown help in interpreting the notes. You can us the slash method if you want. An example is 5/8 as a wall distance measurement, indicating distance to nearer and further walls. From time to time, pace off the width of

FIGURE 2
cross section
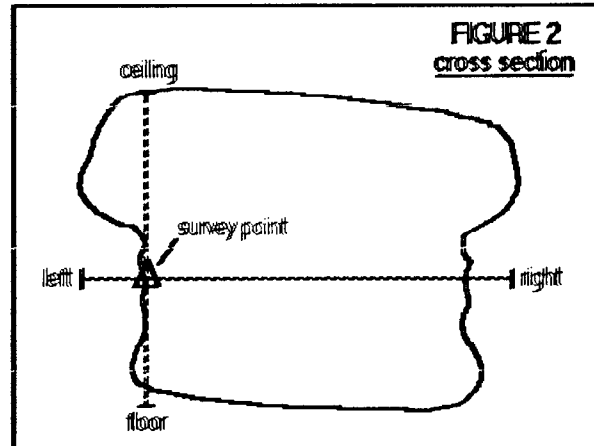
the passage and this will help you estimate the height. Be sure and list the measurements for the first survey number listed on the line if no special page format structure is used...in other words, if you use blank pages and list the points in one line. This is the way we have found best and our smaps computer program is set this way.

7. Draw lots of cross sections. These cross sections should be the same width and height as the plan and profile views. We do these at most survey points in the main passage and frequently in side and overlying passage. They should be at least every 100 feet. We are trying to stack our cross sections on the multi-levels, so you can plan them accordingly near connection points.

8. Include all detail such as floor fill, air movement, AA lava, etc. and features such as geology, drip formations, drops, flow ledges, archaeological sites, and fauna. Use standard NSS symbols and the ones suggested below.

9. For each passage ending or lead, describe exactly, such as "t.t. 7 inches high, no air.", or "lava seal", or "dig in BKDN".

SUGGESTED MAP SYMBOLS
(in addition to standard symbols)

} { ROOTS

ʊ or ⌒ LAVA BALL

——— FLOOR LEVEE

▼⌊⫪⫪ DRIP FORMATIONS

⌒⌒⌒ CAULIFLOWER AA LAVA

⌐}} PAHOEHOE LAVA

10. Number each page as you use your survey book.

11. IMPORTANT!! The page containing the survey data should be opposite the sketched passage containing that data, even if only one shot is recorded on the survey data page. Survey data shots should only be recorded one time to avoid later confusion.

12. The order of shot stations listed on the page determines whether the shot is recorded as foreshot or backshot.

13. The azimuth and inclination readings should both be either backshots or foreshots. If a backshot, mark it as such on both az. and inclination. Mark BS for backshots and leave blank for foreshots. Every inclination should either read and recorded with plus or minus (+or-). Realize that lava cannot flow uphill, however, there are places where it has seeped downwards, leaving depressions. The general trend, however, is downhill. Using this knowledge and the floor measurements, the sketcher can often double check the accuracy of inclinations.

"How deep is it? We need to know for the map."

CA AMUNDSON '87

The Carbide Dump

Cartographers Corner

by Pat Kambesis

Effective use of line widths is a subtle but important drafting technique for both hand and computer drafted maps. In computer drawing or drafting programs, a selection of line widths is a user-option within the programs. For hand drafted maps, variations in line widths are rendered using pens of different line weights (see Table below). For either method, the range of line widths used is a function of the size of the map.

Though most cartographers have their personal preferences in how to utilize line widths, a good general rule is to use the thickest line width to draw the walls of the cave passage (in plan, profile). The next width (or two) down can be used to draw in cross sections and passage features (changes in ceiling heights, ceiling/floor channels slopes, ledges, pits, etc.) Some cartographers like to use an even narrower width to draw in floor detail (flowstone, sediments, formations). And for rendering wall detail on vertical profiles and perspectives, the finest widths or weights are used.

The variation in line/pen widths provides a visually gradational emphasis from walls down to the inner

DRAFTING PEN/LINE WIDTHS

Pen size	Line width (mm)	Suggested uses
2	.6	passage walls
1	.5	passage walls/features/cross sections match lines, leader lines
0	.35	passage/floor detail
00	.30	floor detail
000	.25	floor detail
4x0	.18	wall detail (profiles)
6x0	.13	wall detail (profiles)

features of the passage. Also, using narrower line widths for inner passage detail allows the cartographer to include a good amount of floor detail without making the rendering look too cluttered. Wall details in profiles absolutely require the finest of pen/line widths.

Two maps which exemplify effective use of line widths are the hand-drafted map on the adjacent page of Du San Dong by Carol Vesely and the computer drawn map on the cover of this *Compass & Tape* issue of Monolith Rift by David Parr.

Vesely's use of different pen widths comes across very nicely in the Du San Dong map. The thickest line width she uses is on the walls both in plan and profile. For the cross sections, the next line width down was used. There is a lot of intricate floor detail in the plan view which she was able to portray because of the use of a narrower width line (relative to the passage and cross section width line). The profile also displays a lot of wall detail which she was able to include because she used a 4 x 0 pen. The end result is a richly detailed plan and a profile with a sense of "volume" to the rendering.

The Monolith Rift map is another good example of effective use of line widths i.e. thickest on walls in the profile, narrower widths in plan and for passage detail. Parr doesn't use the same range of widths as Vesely, but he does employ shading to give volume to the profile and a sense of more floor detail.
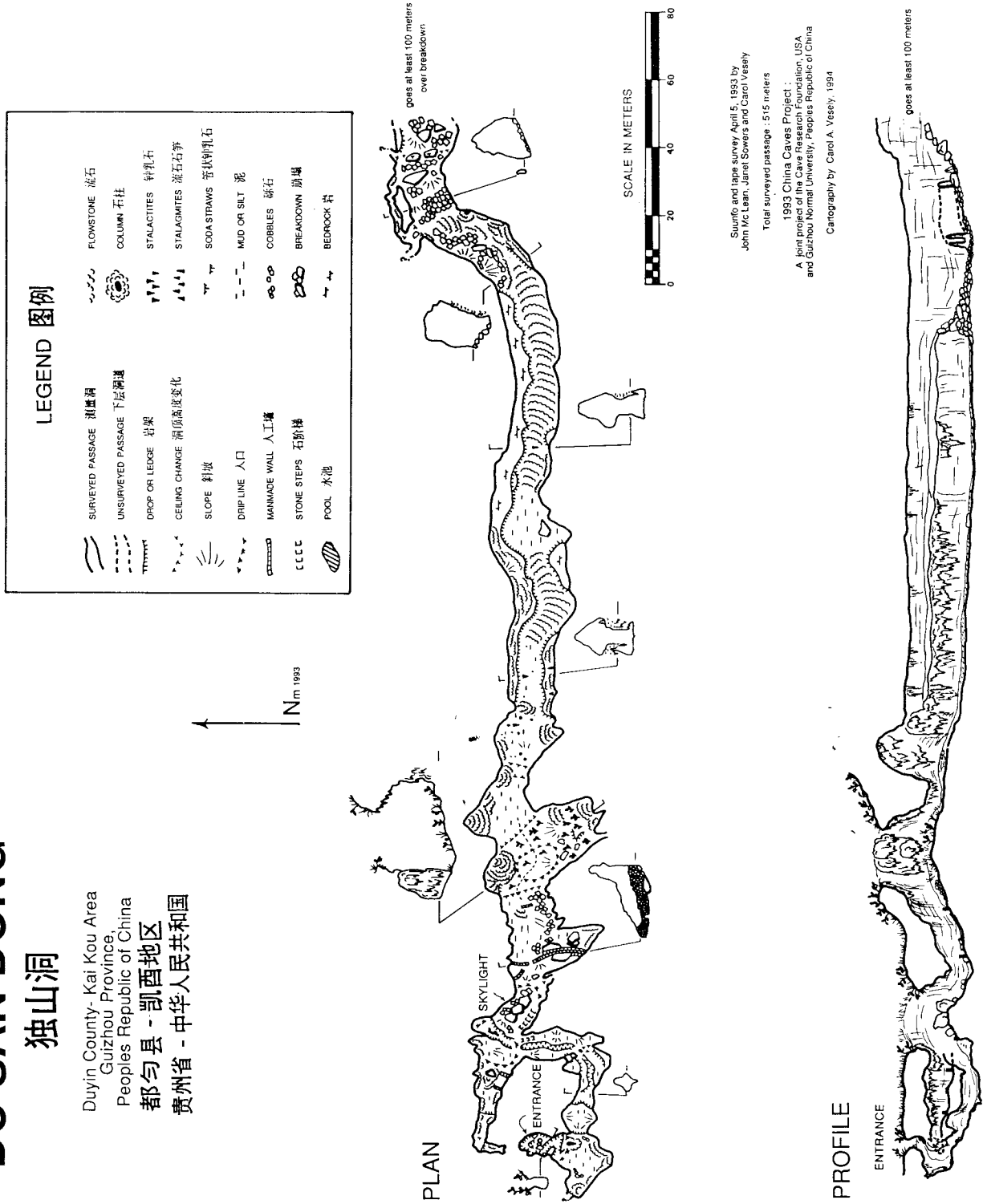
There are a few problems that one should be aware of and take into consideration when using very thin line widths. For computer-drawn or drafted maps, one needs a good quality output device in order to produce the fine-line widths. The very fine-width pen (4x0, 6x0) used for hand-drafting are problematic in that the pen tips get clogged frequently and require a lot of maintenance. Also, if one is going to use fine-width pens regularly, a sonic pen cleaner is well worth the monetary investment (they ain't cheap). In the absence of the expensive sonic cleaner, I have found that fine width pens when they quit working (which they will and irreparably so) make great darts.

DU SAN DONG

独山洞

Duyin County- Kai Kou Area
Guizhou Province,
Peoples Republic of China

都匀县 - 凯酉地区

贵州省 - 中华人民共和国

LEGEND 图例

SURVEYED PASSAGE 测量洞			FLOWSTONE 流石	
UNSURVEYED PASSAGE 下层洞道			COLUMN 石柱	
DROP OR LEDGE 岩架			STALACTITES 钟乳石	
CEILING CHANGE 洞顶高度变化			STALAGMITES 流石石笋	
SLOPE 斜坡			SODA STRAWS 管状钟乳石	
DRIP LINE 入口			MUD OR SILT 泥	
MANMADE WALL 人工墙			COBBLES 砾石	
STONE STEPS 石阶梯			BREAKDOWN 崩塌	
POOL 水池			BEDROCK 石	

N m 1993

goes at least 100 meters
over breakdown

SCALE IN METERS

0   20   40   60   80

Suunto and tape survey April 5, 1993 by
John Mc Lean, Janet Sowers and Carol Vesely

Total surveyed passage : 515 meters

1993 China Caves Project :
A joint project of the Cave Research Foundation, USA
and Guizhou Normal University, Peoples Republic of China

Cartography by Carol A. Vesely, 1994

PLAN

SKYLIGHT

ENTRANCE

PROFILE

ENTRANCE

goes at least 100 meters

COMPASS & TAPE